The social construction of bakelite

The Social Construction of Bakelite: Toward a Theory of Invention

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The aim of this chapter is to put forward some theoretical concepts whereby the development processes of technological artifacts can be understood. The approach I suggest extends the social constructivist analysis of the development outlined by Pinch and Bijker (this volume). In the earlier work we proposed a descriptive model that focused on the various meanings attributed by different social groups to an artifact. This allowed us to give a symmetric account of "successful" and "failed" artifacts, and it also had the advantage of incorporating both technical and nontechnical elements in the description. In this chapter I develop the model further by considering aspects of the history of Bakelite.

The chapter is composed of four parts. In the first section I describe the early history of plastics. For my purposes here the emphasis is not on the historical details but on the presentation of some explanatory concepts. In particular, the notion of the interpretative flexibility of an artifact is elaborated on and the concepts of technological frame and inclusion are introduced for the first time. The exact meaning of these terms is the topic of the second section. In the third part some flesh is put back onto the bones of these concepts by following the plastics history into the Bakelite era. Finally, in the fourth section I suggest a more general scheme for a theory about technological development.

A Description of the Plastics History Pre-Bakelite

The history of human use of plastic materials is as long as the history of humanity itself. The Egyptians used resins, natural plastics, to varnish their sarcophagi, and the Greeks made jewelry out of amber. These two applications—varnishes and the production of small solid objects—have provided and continue to provide important markets for the plastics industry. Some of the natural plastics, such as shellac, can be used for both purposes, whereas others, such as rubber, are used for one purpose only.

Until the mid-nineteenth century, the use of plastics had been confined to luxury and fancy goods, ranging from shellac-lacquered scent boxes to ivory jewelry. The vulcanization of rubber, however, created new markets. During the vulcanization process, rubber is heated in the presence of sulfur, which renders it more flexible and durable. This makes the rubber suitable for a wide range of applications. In the second half of the nineteenth century, both rubber and shellac were increasingly used for electrical insulation, especially "hard rubber," also known as "vulcanite" or "ebonite." This rubber was manufactured by mixing a much higher percentage of sulfur with the crude rubber than was done in the ordinary vulcanization process, and it was used for several new industrial purposes for which none of the older natural plastics had previously been employed. Apart from its use as an electrical insulating material, hard rubber was used for the internal coating of chemical apparatus and accumulator storages and for the manufacture of surgical instruments and artificial teeth. Thus, although plastic materials had previously been restricted to the jewelry-wearing upper classes, they now found favor among new social groups. This, however, created a problem.

A Scarcity Problem and Three Variants of Solution

The exotic location of the sources of shellac and rubber led several chemists and industrialists to perceive an imminent scarcity of natural plastics. "We are exhausting the supplies of India rubber and gutta percha, the demand of which is unlimited but the supply not so," remarked the chairman of a meeting of the Royal Society of Arts in 1865 (cited in Kaufman 1963, p. 33). At this meeting Alexander Parkes gave a lecture on his new plastic material Parkesine, which was the first of a series of variants produced in an attempt to solve the scarcity problem by trying to modify nitrocellulose (Parkes 1865b). Another important incentive for these researchers was the long-standing objective of nineteenth-century inventors, to find a substitute for ivory (Friedel 1983).

Nitrocellulose could be produced rather cheaply from paper, wood fiber, or rags. Its importance as an explosive substance immediately caught the world's attention when the Swiss chemist Christian Friedrich Schönbein found a commercially viable production process in 1846. Somewhat later, several chemists and inventors explored the possibilities of dissolving nitrated cellulose in a mixture of alcohol and ether. The "collodion," as this solution was called, was a clear fluid with the consistency of syrup that, when poured out and allowed to dry, resulted in a transparent film. Several applications, such as wound plaster, a means to render fabrics waterproof and a basis layer for photosensitive materials, were successfully developed.

Parkes was the first to attempt to produce "a hard, strong, brilliant material" from nitrocellulose that could be cut and molded (Parkes 1855). The development of a new plastic market for technical applications, besides the traditional market of luxury consumer goods, is exemplified by Parkes's business policy. On several occasions, in presenting his new plastic, Parkesine, Parkes did not distinguish clearly among the different uses to which it could be put: It could be used as a substitute for luxury plastics, such as ivory and tortoise-shell, as well as for industrial substances such as rubber and gutta-percha (a similar substance to rubber but obtained from a different tropical tree). Parkes placed the early emphasis on its use in the production of fancy articles. For example, at the 1862 World Exhibition he presented medallions, buttons, combs, pierced and fret work, inlaid work, pens, and penholders (Kaufman 1963). However by 1866, when Parkes tried to persuade investors to put capital into a newly incorporated Parkesine Company, the prospectus hardly mentioned Parkesine as a beautiful material for making "works of art." Instead, its applications for making carding, roving, and spinning rollers, insulating telegraphic wires, manufacturing tubing, and varnishing and coating iron ships were all stressed (Friedel 1979). Paralleling this shift of emphasis away from the fancy applications, Parkes tried to make his material as cheap as possible (Friedel 1979; Dubois 1972), but this was not enough to maintain the involvement of the new social groups of users. His eagerness to show the applicability of Parkesine to a variety of different purposes meant that he placed less emphasis on finding a dependable chemical formula for at least one specific form of Parkesine. Thus the plastic was not produced with a consistent quality, and a great number of the items sold by the new company were returned as unacceptable because of shrinkage, twisting, and distortion (Worden 1911). In 1868 the Parkesine Company was liquidated.

A second variant of a nitrocellulose plastic was closely linked to Parkesine. The manager of the Parkesine Company, Daniel Spill, attributed the failure of Parkesine to the fact that they had not made their materials white enough. If it could be made whiter, Parkesine would appear as a more credible substitute for ivory. In 1869 Spill founded another company, and with only minor changes in the manufacturing process he continued the production of what by now was called Xylonite. This venture fared no better than the previous one, and it was abandoned in December 1874. Spill had an unshakable faith in his material and established another company in 1875. This time he did succeed in finding a small but rather stable market for what he now also called Ivoride (Kaufman 1963).

A third variant of solution to the scarcity problem of natural plastics was developed by John Wesley Hyatt in Albany, New York. As the popular story goes, Hyatt's research was triggered by the offer of a $10,000 prize for the patent of a material that could be used as a subsitute for ivory in the manufacture of billiard balls. Hyatt first tried several well-known plastic compositions, such as wood fiber with shellac. Although this did not result in a satisfactory substitute, an important consequence was Hyatt's acquisition of familiarity with processes for molding plastics under heat and pressure (Friedel 1979). This experience made Hyatt aware of the problems of liquid collodion solutions, such as the ones Parkes and Spill had used: The drying process inevitably caused shrinkage, which made it difficult for such collodion mixtures to be used for molding solid objects. In his own words:

> From my earliest experiments in nitrocellulose, incited by accidentally finding a dried bit of collodion the size and thickness of my thumb nail, and by my very earnest efforts to find a substitute for ivory billiard balls, it was apparent that a semi-liquid solution of nitrocellulose, three-fourths of the bulk of which was a volatile liquid and the final solid from which was less than one-fourth the mass of the original mixture, was far from being adapted to the manufacture of solid articles, and that I must initially produce a solid solution by mechanical means. (Hyatt 1914, p. 158)

After Hyatt took out several patents describing such processes, in 1870 a patent was issued that referred to "the use of finely committed camphorgum mixed with pyroxyline-pulp [nitrocellulose] ... [rendering] a solvent thereof by the application of heat (Hyatt 1870). Only many years afterward, when he was involved in patent litigation trials, did Hyatt use the term "solid solution" to describe the material produced in one of the first stages of the production process. He used this term in order to bring out the crucial difference from earlier nitrocellulose plastics. His solid solution appeared at the time to be more of a moist mixture:

> We conceived the idea that it might be possible to mechanically mix solvents with the pulp and coloring matter while wet, then absorb the moisture by blotting papers under pressure, and finally submit the mass to heat and pressure. (Hyatt 1914, p. 159)

However, his later use of the term "solution" probably added to the perceived importance of the role of solvents in the Celluloid production. Ironically, Hyatt himself did not mention camphor as a solvent, only as an additive. I return to this point concerning the role of solvents later. Together with his brother, Isaiah S. Hyatt, Hyatt founded the Albany Dental Plate Company in 1870. They advertised

> a newly-invented and patented material for Dental Plates or bases for artificial teeth, that cannot fail to delight every dentist who desires a better material for the purpose than hard rubber. (*The Dental Cosmos* 13 (1871); cited in Friedel 1979, p. 53)

The dental plates did have various imperfections. Some of them had a strong camphoric taste; some became soft in the mouth (sufficiently so for the teeth to become loose), and plates were found to warp after having been adjusted to the patient's mouth (Friedel 1983). Although these dental plates were far from satisfactory, the concerted effort to produce a material with specific, consistent qualities resulted in the Hyatt brothers' forming the Celluloid Manufacturing Company in order to produce Celluloid in semifinished form (rods, sheets, tubes, etc.). From 1872 to 1880 the Hyatts granted licenses to different companies for the production of Celluloid consumer goods, each company devoting itself only to a narrowly defined market (Friedel 1979, 1983).

Interpretive Flexibility of the Artifact Celluloid as Shown in the Selection Process

Which of the two rival plastics, Ivoride/Xylonite or Celluloid, became dominant? The selection process (see Pinch and Bijker, this volume) was determined to a large extent by a patent controversy. This controversy, between Spill and Hyatt, concerned who had priority in the invention of the use of camphor in the production of a plastic out of nitrocellulose. The debate can be used to show the "interpretative flexibility" of the artifact Celluloid. For Spill, Celluloid meant a mixture of nitrocellulose and camphor that, although prepared in a slightly different way, was essentially identical with his Xylonite or Ivoride. However for Hyatt, a crucial difference between Celluloid and other nitrocellulose plastics was to be found in the fabrication process: He used, he said, a solid solution instead of a liquid solution of nitrocellulose and camphor. Linked to these differences in how these two industrial chemists conceptualized the meanings of their plastics were differences in goals and in the resulting lines of development. Spill mostly valued the use of his plastic as a substitute for expensive natural plastics, as is indicated by the name Ivoride and his emphasis on the need for the material to be white. Consequently, mass production by molding was not his first priority. For Hyatt the goal of constructing a material that could be used to produce a large number of narrowly defined products of consistent quality led inevitably to focusing on the production process and especially on the molding characteristics of the material.

The patent dispute between Spill and Hyatt was resolved by Samuel Blatchford, at that time a justice of the US Supreme Court, and "the most highly regarded patent judge of his time" (Friedel 1983, p. 132). He decided on August 21, 1884, that neither Spill nor Hyatt should be named as the inventor of a camphor-nitrocellulose plastic, because Parkes had already covered that combination of substances in his patents. In effect, this meant a victory for Hyatt, because the judge's decision denied Spill the novelty of using camphor and thus nullified his grounds for litigation against Hyatt. The Celluloid Manufacturing Company succeeded in putting itself on a firm financial base.

The increasing stabilization of Celluloid can be traced by following its use as an intermediate material between cheap but ugly looking plastics, such as rubber, and luxurious materials, such as ivory. For example, the advent of Celluloid brought combs, cuffs, and collars within the reach of social groups that had not been able to afford such luxurious articles until then (luxurious because the original cotton cuffs and collars had to be washed every day and this was such a laborious job that it needed, it seems, servants to do it for you; figure 1).

A Problem with the Artifact Celluloid

Having described some of the processes that led to the eventual stabilization of Celluloid, the next step in the descriptive model is to ask what problems were perceived with respect to this artifact (Pinch and Bijker, this volume). One problem with Celluloid, in the view of certain important social groups, was never solved. This was its flammability. As in the case of the development of the bicycle (Pinch and Bijker, this volume), problems seldom have equal pertinence for all social groups. Thus data about fire and accidents caused by explosions in which Celluloid was said to be involved were interpreted quite differently by different people (Kaufman 1963). For example, it is doubtful whether any chemist would not have thought it the height of folly to heat nitrocellulose under pressure, knowing its

Figure 1
Advertisement for Celluloid. The advertisers often used anti-Chinese sentiments in the promotion of Celluloid cuffs and collars. Photograph courtesy of the Warshaw Collection of Business Americana, National Museum of American History, Smithsonian Institution, Washington, D.C.

explosive character. A professor of chemistry who visited Hyatt's factory warned that if too much heat were applied, the substance would inevitably destroy them, together with the building and the adjacent property! Although Hyatt was skeptical, he was worried enough to put the proposition to the test:

The following day between 12 and 1, when all were out, I rigged up a four inch plank used as a vice-bench, braced it between the floor and ceiling, between the hydraulic press and the hand pump, intending it to shield me from possible harm. I then prepared the mould, heating it to about 500°F knowing it would certainly ignite the nitrocellulose and camphor, and thinking I would abide by the result. The gases hissed sharply out through the joints of the mould, filling the room with the pungent smoke. The mould, press, building and contents were there, including myself, very glad that I did not know as much as the Professor. (Hyatt 1914, p. 159)

However, not many users were convinced by this experiment, and national and local authorities made special safety regulations for Celluloid processing industries (Worden 1911).

Another Artifact and Its Interpretative Flexibility: The Phenol-Formaldehyde Condensation Product

At about the same time that Hyatt was establishing his company for the manufacture of dental plates, Adolf Baeyer in Germany was observing condensation reactions between aldehydes and phenolics. Although he found that under specific conditions chemical compounds that belonged to the group of phenolic dyes were formed, most of the condensation products were resinous and difficult to crystallize (Baeyer 1872).

Many historians of the plastics industry identify Baeyer's condensation product as the first synthetic resin. Having produced the "resin," researchers directed their efforts toward rendering it in an industrial process. This was eventually accomplished by Leo Hendrik Baekeland. For Baeyer himself, however, the reaction product meant something completely different from a synthetic resin. Because the resinous character of the condensation product presented a problem for the usual methods of analysis, Baeyer could not evaluate its importance as a potential synthetic dye. This made the phenol-formaldehyde resin only an annoying by-product that had to be thrown away. A third meaning was attributed to this condensation product by Arthur Michael, who was a student of Hofmann, Bunsen, and Mendeleev and who ended his career as chemistry professor at Harvard University. For Michael the resin did not mean an unpleasant obstacle to synthetic dye research; neither did it mean a potentially useful synthetic plastic. Michael was interested in these synthetic resins for purely academic, biological reasons: He hoped that this research might lead him to a better understanding of natural resins (Michael 1883–1884). He had no interest in potential industrial applications.

Thus the interpretative flexibility of the artifact phenol-formaldehyde condensation product amounts to the existence, in terms of our descriptional model, of three different artifacts: an embryonic plastic material, a potential dye yet to be analyzed, and a method for studying natural resins.[1] However, it was not until the turn of the century that the first artifact came into existence. It is through retrospective distortion that the first artifact is seen to have its origin in 1872. In the next part of this section I address the issue of why the first artifact, Bakelite as it later became known, was not discovered earlier.

Technological Frames and Why No Phenol-Formaldehyde Condensation Plastic Was Constructed

More than a decade passed after the initial observation of the condensation reaction between phenol and formaldehyde, and nobody seemed interested in studying its potential for the production of a synthetic plastic, although at the same time Celluloid's success suggested an attractive market. One might think of the high price of formaldehyde as an explanation for this neglect of the possibility of developing a commercial synthetic plastic. If that explanation is correct, then we would expect the availability of cheaper formaldehyde to lead to a concerted research effort to make a phenol-formaldehyde plastic.

It was not until 1888, after a catalytic process had been developed that enabled formaldehyde to be synthesized directly, that formaldehyde became an easily available material. The dye industry, for example, started to use it in the synthesis of several dyes. We might ask whether there was any trace of a renewed interest in making a synthetic plastic out of the phenol-formaldehyde condensation product at this point.

Indeed, an industrial chemist, Werner Kleeberg, was stimulated by the commercial availability of formaldehyde to take up the study of the condensation reaction. Kleeberg was almost certainly interested in this reaction because, like Baeyer, he hoped to find a new dye. Also for Kleeberg, the "rosarote Masse" meant a substance to be analyzed. And that, again, appeared to be impossible with the available analytical techniques. As a result, Kleeberg concentrated on other formaldehyde reactions that did not produce resinous substances (Kleeberg 1891). Other chemists' interests were triggered by the availability of cheap formaldehyde as well. Otto Manasse and Leonhard Lederer developed, independently, a process to make phenol alcohols (Manasse 1894; Lederer 1894). Probably, both were working for chemical firms, producing raw materials for the synthetic dye industry. These newly discovered chemicals were considered to be of general interest, but they also had commercial value (Lederer 1894). Until then, the production of phenol alcohols had been carried out by the reduction of the respective aldehydes, an expensive and cumbersome process. The abundant availability of formaldehyde suggested another solution: synthesize the phenol alcohols from formaldehyde. Lederer, in summarizing efforts to realize this goal, explained that all such efforts had failed because of the sudden appearance of those "unerquickliche Harze" (awful resins; Lederer 1894, p. 224). Thus, for these chemists too, we can say that the resinous material meant something different. It was no potential plastic to be tamed for molding; nor was it a potential dye to be analyzed for synthesis; it also was not an instrument for studying natural resins; rather it was an uninteresting substance to be avoided because one was after something else.

Apart from further demonstrating the interpretative flexibility of the artifact resinous condensation product of phenol and formaldehyde by adding a fourth construct to the list, the works of Kleeberg, Manasse, and Lederer also indicate that it was not the high price of formaldehyde before 1886 that explains the neglect of the potentiality of that resin as a commercial plastic. Cheap formaldehyde did not lead to the development of a commercial plastic. Another explanation must be sought.

The observation that "they just did not see it" is only a rephrasing of what has to be explained. Why didn't the possibility of producing a synthetic resinous material out of the phenol-formaldehyde reaction figure on the agenda of chemists at the time? Certainly chemists such as Baeyer, Manasse, Lederer, and Kleeberg did not lack commercial acumen. Surely they also would have been familiar with (hard) rubber and Celluloid, if only in their households. Something prohibited the synthetic plastic from becoming an issue for this community of chemists. In order to describe this, I introduce the notion of a *technological frame*.

A technological frame is composed of, to start with, the concepts and techniques employed by a community in its problem solving. (A more comprehensive description of a technological frame is given later, on pages 171–174.) Problem solving should be read as a broad concept, encompassing within it the recognition of what counts as a problem as well as the strategies available for solving the problems and the requirements a solution has to meet. This makes a technological frame into a combination of current theories, tacit knowledge, engineering practice (such as design methods and criteria), specialized testing procedures, goals, and handling and using practice. The analogy with Kuhn's "paradigm" among others is obvious. I return to such analogies in the next section.

If we now apply the concept of a technological frame to the discussion of Baeyer and Kleeberg, it becomes clear why they did not try to modify the phenol-formaldehyde condensation product into a usable plastic. First, they had other goals: the production of new synthetic dyes. But these goals can be changed, especially when large profits are on the horizon. So there is more to it than this. The idea of making a plastic by chemical synthesis simply did not and indeed *could* not occur to them. Chemical theory at that time could not cope with such a substance. Neither could chemical practice: Their daily laboratory practice included all kinds of chemical analysis and synthesis, but the application of pressure and molding techniques were of another world. The technological frame of synthetic plastics was not yet in existence. The same applies to Manasse's and Lederer's not seeing the potentiality of the condensation product: It simply did not fit in the technological frame of their community.

Searching for a Celluloid Substitute within the Celluloid Technological Frame

Celluloid, notwithstanding its success and stabilization in various social groups, still had some important problems. As mentioned previously, for some groups it was quite dangerous because of its flammability; also it was rather expensive because of the price of camphor; and, third, it was not suited to high temperatures, which posed a barrier to many technical applications. This situation prompted several chemists to start searching for an alternative to Celluloid. Other cheaper solvents were tried to replace camphor. All kinds of chemical additives were studied to temper the flammability. And some of these chemists directed their research toward the condensation reaction between phenol and formaldehyde. I argue that this community of chemists had a technological frame that to a large extent was dominated by Celluloid experience.

First, for men such as Smith, Luft, De Laire, Fayolle, and Story, the goal was explicitly to find a Celluloid substitute. Often, they described their products also as "shellac substitutes" or "horn-like substances," but the intended field of application clearly was the same as Celluloid's. Second, most of these inventors did not show any more sophistication with respect to chemical theory than Hyatt had displayed: They made no efforts to say anything about the structure of the condensation product nor about the chemical reaction in detail. Third, their problem-solving strategy focused on finding an adequate solvent. Through the patent litigation trials the choice of the right solvent had acquired the meaning of crucial step in the "invention of Celluloid." And also, much attention was paid to the solvent because of the high price of camphor. This placed the role of a solvent in a central position in the Celluloid technological frame, with respect to both the identification of the crucial problems *and* the problem-solving strategy. Indeed, we see the previously mentioned inventors defining their problem of making a synthetic plastic as how to soften the condensation product, for, having been softened, the material, they hoped, could be treated like Celluloid. Their strategy to accomplish this was to apply all kinds of different solvents at different stages of the reaction. In the words of Baekeland, commenting on Luft's patent:

> The whole process of Luft looks clearly like an attempt to make a plastic similar to celluloid and to prepare it and to use it as the latter. The similarity becomes greater by the use of camphor and the same solvents as in the celluloid process. (Baekeland 1909a, p. 322)

However, this strategy did not work in this context and none of these men succeeded in making a commercially viable synthetic resin.

Different Degrees of Inclusion, or How Baekeland Succeeded

Finally, I come to Baekeland. My contention is that Baekeland worked to an important degree within the Celluloid frame and that he worked equally importantly to some extent *not* according to that frame. I want to tackle the descriptional problem by this situation with the concept of inclusion. Baekeland worked within the same frame as Smith, Luft, De Laire, Fayolle, and Story, but he had a lower inclusion in that frame. I describe him as working according to the Celluloid frame because he had the same goal—making a substitute for Celluloid and the natural plastics and varnishes—and because he started to work with the same problem-solving strategy—searching for an effective weakening solvent. But Baekeland did not adhere strictly to the ideas and methods of this technological frame. This relatively low inclusion in the Celluloid frame is linked to Baekeland's high inclusion in another technological frame: electrochemical engineering. For example, after having presented several applications in the traditional field of Celluloid applications, he added:

> But its use for such fancy articles has not much appealed to my efforts as long as there are so many more important applications for engineering purposes. (Baekeland 1909d, p. 157)

Obviously, Baekeland intended to focus on other fields of application, overlapping with the Celluloid range of products but distinctly more of an industrial engineering character. When his searching for a weakening solvent did not yield any result, his inclusion in the Celluloid frame was low enough for him not to get stuck on this problem: Baekeland instead started to use one of the familiar problem-solving strategies of the electrochemical engineering frame. He carried out a long systematic investigation to study all the different factors bearing on the reaction. This was the first time that anybody had researched this, despite Baeyer having observed the condensation reaction thirty-three years earlier.

This investigation enabled Baekeland to control the violent condensation reaction. He distinguished three phases in the reaction and, because he could stop the reaction after the first and second phases, he was able to manipulate the molding mass before it changed during the third and final phase of the now well-known (but at that time notorious) thermosetting plastic. The key element in this procedure was formulated in the famous "heat-pressure patents" (Baekeland 1907a, 1907b). Only when high pressure is applied *while* heat triggers the condensation reaction is the production of gaseous products counteracted; otherwise the product is porous and worthless for molding applications.

We leave the Bakelite story at this point in order to return to the notions of technological frame and inclusion.

Technological Frame and Inclusion

Deliberately I have made the concept of technological frame broad enough so as to include such different elements as current theories, goals, problem-solving strategies, and practices of use. ("Practices of use" is to some extent congruent with "existing markets," but it focuses on consumer practices rather than on the economic aspects; an example is given later.) Depending on the technological frame that is described and the purposes for doing so, different elements may require different degrees of attention. For example, the element of current theory in the Celluloid frame is rather empty if we regard Hyatt in his early Celluloid days. As he said aptly at the end of the experiment to test its flammability: "[I was] very glad that I did not know as much as the Professor."

The need to make a technological frame into such a broad concept arises from the requirement that it must be applicable to social groups of nonengineers also. For a social constructivist analysis of technology, it is important not to make any a priori distinction among different types of social groups (Callon 1981b; Pinch and Bijker, this volume). Of course, when describing the technological frame of the social group of dentists with respect to the artifact hard rubber, more details need to be given about the frame elements of goals and using practice than about the element of current theories. Thus a tech-

What can rubber do for dentists, what is dentists' [illegible] nological frame should be understood as a frame with respect to technology, rather than as the technologist's frame.[2]

The case of the high-wheel Ordinary bicycle (Pinch and Bijker, this volume) provides an illustration. The using practice of the social group of "young men of means and nerve," that is, racing, showing off, and impressing the ladies, constituted the macho machine, whereas the using practice of the social groups of women and elderly men, that is, touring, falling off, and "breaking limbs and bones," constituted the unsafe machine. The macho machine led to a design tradition with larger wheel radius, and the unsafe machine gave rise to a variety of designs with, for example, smaller wheels, backward saddle, or the smaller wheel in front. Thus different using practices may bear on the design of artifacts, even though they are elements of technological frames of nonengineers.

This aspect represents an important difference from most of the related concepts used by other students of technological development. The concepts of technological style (Hughes 1983 and this volume), technological tradition (Constant 1980, 1984; Laudan, 1984a), technological paradigm (Dosi 1982, 1984; Gutting 1984; Van den Belt and Rip, this volume), technological orientation complex (Weingart 1984), and technological regime (Nelson and Winter 1977, 1982; Van den Belt and Rip, this volume) are intended for application to social groups of engineers only. In addition, Hughes's usage of the term "technological style" is primarily meant to account for national differences in technology, which places the concept on a much higher level of aggregation than the intended level for technological frame.

A second feature of technological frame, not yet mentioned explicitly, is at least equally important and differentiates it from most of the other concepts as well. The concept of technological frame is intended to apply to the *interaction* of various actors. Thus it is not an individual's characteristic, nor the characteristic of systems or institutions; frames are located *between* actors, not *in* actors or *above* actors. In that respect frames are similar to Callon's networks (Callon 1986). Although my usage of the concept of a technological frame draws on other studies in which similar concepts have been developed empirically as well as theoretically[3] the application to technology is, as yet, only tentative. I briefly sketch some aspects of the interactional nature of this concept.

As noted previously, the meanings attributed to an artifact by members of a social group play a crucial role in my description of technological development. The technological frame of that social group structures this attribution of meaning by providing, as it were, a grammar for it. This grammar is used in the interactions of members of that social group, thus resulting in a *shared* meaning attribution (that the meaning of an artifact is shared among members of a social group is, after all, a key element in the identification of relevant social groups; see Pinch and Bijker, this volume). The interactional nature of this concept is needed to account for the emergence and disappearance of technological frames. A technological frame is built up when interaction "around" an artifact starts and continues. Thus the artifact Parkesine did not give rise to a specific technological frame because the interactions "around" it came to an end before really taking off. The opposite happened to Celluloid: Its stabilization was accompanied by the establishment of, for example, a social group of "Celluloid chemists." The continuing interactions of these chemists gave rise to *and* were structured by a new technological frame. An important element of this technological frame was, as we have seen, the focus on solvents in the chemical process.

In a way, the concept of a technological frame thus results in making less visible the seams of the web that was woven with the descriptional model (see the introduction to part I of this book). On the one hand, a technological frame can be used to explain how the social environment structures an artifact's design. For example, the dominance of the social group of Celluloid chemists resulted in various patents for a phenol-formaldehyde plastic in which the use of a solvent played a crucial role. On the other hand, a technological frame indicates how existing technology structures the social environment. For example, the stabilization of the artifact Celluloid resulted in the rise of specific social groups and technological frames. In this respect an artifact, such as Celluloid in the last instance, plays a role that is similar to Kuhn's exemplar (Kuhn 1970; Gutting 1984, p. 56).

A technological frame structures the interaction of members of a social group. But it can never do so completely: first, because different actors will have different degrees of inclusion in the frame (actors with a high inclusion interacting more in terms of that technological frame and actors with a low inclusion to a lesser extent), and, second, because all actors will, in principle, be members of more than one technological frame, as I have suggested in the case of Baekeland.[4] Also in these aspects—the possibility of various degrees of inclusion in a technological frame and the possibility of being within different frames—the concept of a technological frame differs from the paradigmlike concepts mentioned previously.

The characteristics of the concept of inclusion can be illustrated by contrasting the engineer with a relatively low inclusion in a technological frame with the notorious "marginal scientist" as criticized by Gieryn and Hirsch (1983). There are at least three important differences. First, the marginality concepts discussed by Gieryn and Hirsch are one dimensional. For example, in one study scientists are considered marginal if they recently migrated from another field, whereas in another study "marginal" is operationalized as "being young." The different dimensions yield contradictory results: If Gieryn and Hirsch could choose any single dimension to characterize a scientist, all ninety-eight scientists of their sample would be marginal. In contrast, the concept of inclusion is *multidimensional* because it is related to the multifaceted concept of technological frame. Thus the inclusion of actors in a technological frame can be specified by describing their goals, problem-solving strategies, experimental skills, theoretical training, and so on; then one should go on to indicate to what extent each of these elements is congruent with the respective elements of the technological frame. For example, Baekeland's goals were congruent with the Celluloid producers' technological frame in that Baekeland intended mass production of plastic articles; his goals were not congruent in that he was focusing on the production of industrial applications, rather than on consumer goods. Second, as I have already indicated, inclusion is not a binary concept: Instead of being either marginal or central, a member of a social group can have different *degrees* of inclusion in the technological frame. This is especially important when we want to pay due respect to the dynamic character of technological development. The degree of inclusion of an actor is not constant but can change in the course of events. For example, Baekeland's degree of inclusion in the Celluloid frame decreased when he switched from the application of solvents to another problem-solving strategy that belonged to the electrochemical technological frame. The third point of difference with the marginality concept was also mentioned previously. Actors will typically be members of different social groups and have (different degrees of) inclusion in various technological frames.

In the next section I again take up the case of Bakelite and follow its history from 1907 on.

The Social Construction of Bakelite

In the orthodox view of the plastics history, Baekeland's patents of 1907 constitute the invention of Bakelite. But as all authors in this volume argue in different tones, an artifact can never be explained as being invented in such a clear-cut way. In 1907 there was not yet a successful innovation Bakelite. The exhibits Baekeland showed during his presentation at the New York Chemists' Club could have proved as illusory as the earlier Parkesine exhibits shown at the 1862 World Exhibition. The first synthetic plastic that would mark the beginning of the "plastic era" still had to be constructed. To understand this part of the developmental process of Bakelite, we are once again helped by the concepts of technological frame and inclusion.

No sophisticated chemical experience seemed to be involved in the Bakelite process, nor hardly any theory (the macromolecular theory to describe this type of process was not developed until the 1920s). That is why Baekeland initially envisaged that he himself could stay out of the manufacturing process; his intention was to issue licenses on a royalty plan for the use of his patents, but

> I soon found I was greatly mistaken in this, and that it would have caused no end of disappointment to teach to others chemical details which, to me, seemed rather simple. (Baekeland 1916, p. 155)

This is understandable in the light of the previous discussion. The work of the social groups to which Baekeland intended to turn over the manufacture of the Bakelite molding powders was structured by the Celluloid technological frame. This technological frame focused the interaction within the producers' social groups on, for example, the employment of solvents and the development of new processing machines, such as the compression sheet molding press and the hydraulic planer (both used for the making of thin sheets), and the blow molding press (used to provide new generations with toys, baby rattles, dolls) (Dubois 1972). It did not provide the means to deal with a delicate chemical reaction such as the one between phenol and formaldehyde "in which almost anything may happen but the formation of bakelite" (Chandler 1916, p. 179).

Then Baekeland planned to fabricate the molding powders as intermediate products and to leave the final molding process to the experienced engineers involved in the production of hard rubber, Celluloid, and insulating materials. However, again the Celluloid technological frame posed a barrier:

> I found, to my astonishment, that people who were proficient in the manipulation of rubber, celluloid or other plastics were the least disposed to master the new method which I tried to teach them or to appreciate their advantages. This was principally due to the fact that these methods and the properties of the new material were so different in their very essence from any

> of the older processes in which these people had become skilled. This rather unexpected drawback is so true that even to-day the most successful users of bakelite are just those who were not engaged in plastic before, this simply for the reason that they did not have to divorce themselves from the routine of older methods, and were willing to listen patiently to suggestions from newcomers in the field. (Baekeland 1916, p. 155)

To establish a social group of Bakelite producers, Baekeland had to enlist people from outside the existing plastics-producing groups or those with a low inclusion in the Celluloid technological frame. Thus the social group of Bakelite producers was in the beginning almost totally congruent with the employees of the Bakelite Corporation.

Synchronously with the stabilization of the artifact Bakelite and the formation of a social group of producers, a technological frame came into being. Thus the system of artifact, social group, and technological frame gains *technological momentum* (Hughes 1983 and this volume). These closely interlinked processes can be traced by following the various patent litigation trials and negotiations after 1909. In these trials the meaning of Bakelite for this group of producers was repeatedly made more precise; after the settlement of each patent struggle the losing party became a member of the producers' social group by acquiring a leading position in the Bakelite Corporation; methods and concepts developed by the other chemists were incorporated in the technological frame of the producers' social group.

Thus the social group of producers was, for example, extended by giving Hans Lebach a function within the Bakelite Gesellschaft mbH, established in Germany in 1910. In 1907 Lebach, who worked for the chemical firm Knoll & Co., had also patented a phenol-formaldehyde condensation product (Knoll 1907, 1908; Lebach 1909). During a heated debate in the *Zeitschrift für Angewandte Chemie*, Baekeland said he was "firmly convinced of the technical worthlessness of this substance" (Baekeland 1909b, p. 2006). This however did not prevent the assimilation of Lebach's process into the technological frame of the Bakelite producers once the struggle was over. This is demonstrated by one of the review articles Baekeland published later on, in which he described neutrally "another indirect method" and plainly acknowledged that "this method was first published by Lebach at the end of 1907" (Baekeland 1912, p. 742). Analogously, the management of the American General Bakelite Company was formed almost totally from the ranks of previous competitors who had been "defeated" in the patent struggles (Redman and Mory 1931), their methods and concepts being partially integrated in the technological frame as well (Thinius 1976).

One of the last important stages in the social construction of Bakelite was the enrollment of two new but increasingly important social groups: the automobile and radio industries. For the radio industry, Bakelite was a good insulating molding material, and, especially for the wireless amateur, it also meant a versatile plate material that could be sawed, drilled, and filed to provide a mounting frame for electrical parts.

Baekeland had, as is also evident from his previous projects, an acute insight into the possibilities of the marketplace. This is illustrated once more in his view of the tasks of an industrial chemist, in which he shows once more that there is much more to a successful innovation than simply producing a new substance:

> This question is not just related to the task of creating a certain chemical substance. The subject is much more complicated, because the objective is to manufacture a product in such a way that it can be used reliably for very specific technical purposes. (Baekeland 1909b, p. 2007)

Primarily, Baekeland's efforts were directed toward the production of electrical insulating parts. Electric manufacturing companies, such as Westinghouse Electric Co., Remy Electric Co., and the General Electric Co., were his first customers, buying the molding material from the General Bakelite Company. He worked personally in many plants to help solve the early problems. In establishing these contacts, Baekeland mainly operated at the level of engineers, rather than at management level.[5] His work as an engineer among fellow engineers was efficacious, I think, in stimulating the emergence of a technological frame of Bakelite molders.

By means of the electrical industry, the second important social group of Bakelite users was enrolled—the automobile industry. For the automobile industry Bakelite meant an accurate molding material to produce good electrical insulating parts unaffected by moisture, oil, or other chemicals and able to withstand high temperatures. Kettering's and Bosch's ignition and starting systems were popularizing the motorcar but required insulating parts that needed to be strong and chemically resistant. Subsequently, the use of Bakelite in this industry branched out to nonelectrical parts, such as steering wheels, radiator caps, gear shift knobs, and door handles. Through the initial enrollment of these two social groups, Bakelite acquired a high degree of stabilization by the end of the 1930s in many more social groups.

To finish the story of Bakelite construction I briefly turn to its use in

Figure 2
The electric hot water bottle made by R. A. Rothemel, Ltd. Obviously, Bakelite could not be used as an imitation of the (soft) rubber material, but even in the industrial design of products that used to be made of rubber, the imitation is evident. Photograph courtesy of Collectie Becht, Naarden, The Netherlands.

the production of consumer goods. In its meaning of a molding material for electrical insulating parts, Bakelite only partially substituted for other materials; many applications were completely new. Bakelite's meaning as a material for consumer goods (figure 2) is much more ambivalent. Here, the old tension between an imitation material and a material of its own, so intimately tied up with the whole plastics history since Celluloid (Friedel 1983), is prominent. A market survey, carried out in 1938 for the German Bakelite Gesellschaft mbH, nicely illustrates this ambivalence, as does a "retrospective market study" held in 1981 in the Netherlands.[6]

The most important motives to buy Bakelite products were their elegant designs (the material was modern and did not require much maintenance) and their long durability in comparison with porcelain, glass, and clayware. Of course, there were also disadvantages. For example, Bakelite was considered to be rather fragile. Significantly, this view of Bakelite as being fragile was most prominent in industrial areas, where factory workers knew from experience the many intricacies of manipulating Bakelite (they were included in two technological frames!).

Bakelite was often used as packing material, especially for articles that needed to be kept dry (for example, medicine, tobacco, and cosmetics). Many Bakelite boxes were meant to be permanent; one could buy refills. Therefore extra attention was paid to their exterior design (figures 3 and 4). By the end of the 1930s Bakelite was increasingly more accepted as a material of its own. This is reflected in the development of the exterior design. It is possible to detect a general

Figure 3
"De Vergulde Hand" soapbox. Form and decoration of refillable boxes were used to enhance the recognition of the product, even more so than the trademark. Photograph courtesy of Collectie Becht, Naarden, The Netherlands.

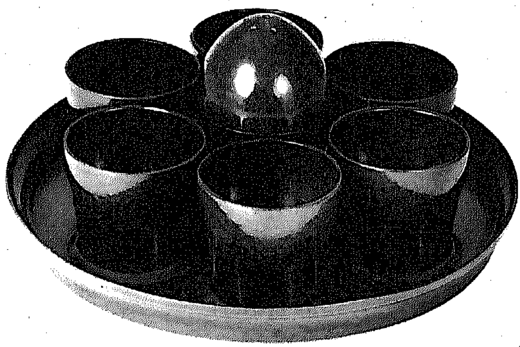
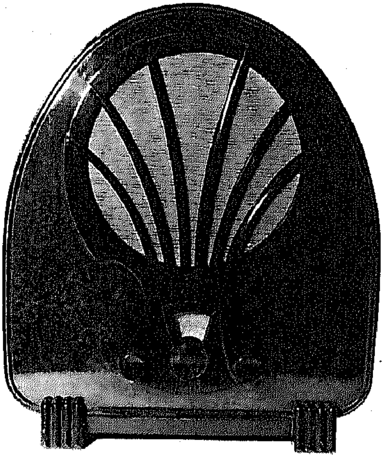
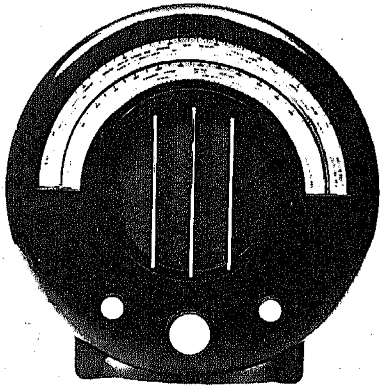


Figure 4
Eggcups on a plate with a saltcellar in the center. "That was standing in my mother's best room!" an interviewee recalled when the artifact and photograph were shown to him (Kras et al. 1981, p. 43). Bakelite was also used in luxury products because of its high-tech connotation. Photograph courtesy of Collectie Becht, Naarden, The Netherlands.

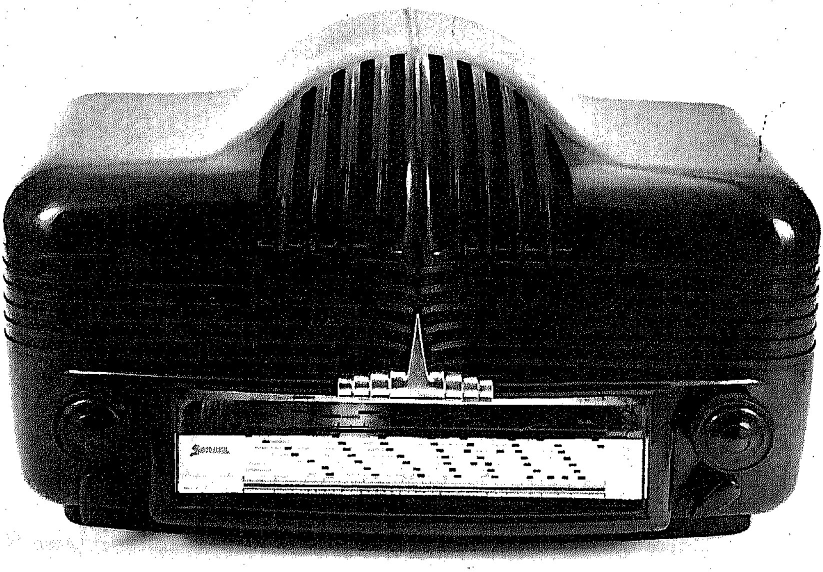
trend from imitative design (for example, the Art Deco style; figure 5) to independent design (for example, the Streamline style; figures 5c and 6). Thus the meaning of Bakelite by the end of the 1930s was very much that of "modern technology," "unlimited possibilities," the "Fourth Kingdom" (besides the kingdoms of minerals, plants, and animals).[7] I would argue that, for a full-fledged account of the history of Bakelite (which was not my objective in this chapter) and for an adequate description of its final stabilization, the social group of industrial designers needs to be given attention. This would bring us rather close to the history of art, rendering the web even more seamless.[8]



a

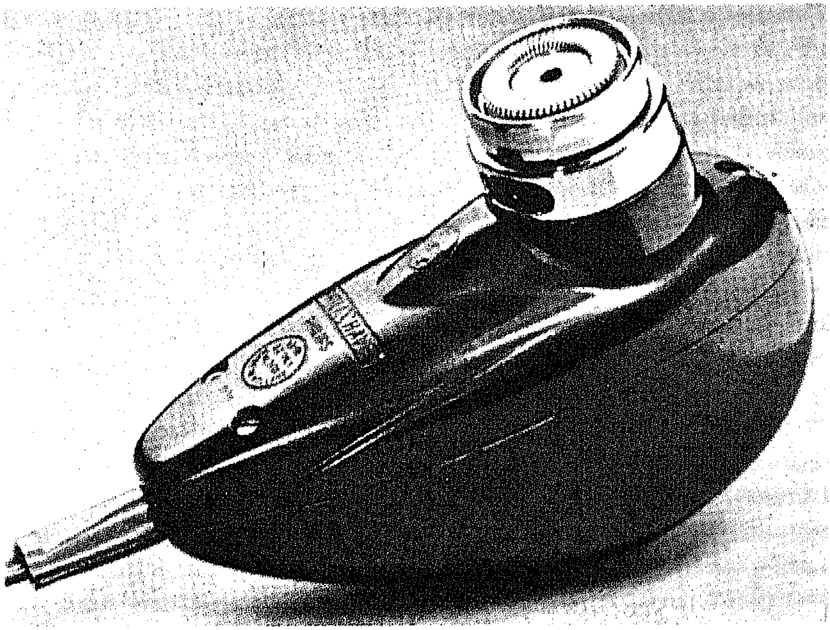


b



c

Figure 5
(a) Art Deco Philips radio (1933). (b) Functionalistic Ekco radio (1934). (c) Streamline Sonora radio (after 1945). Photographs courtesy of Collectie Becht, Naarden, The Netherlands.



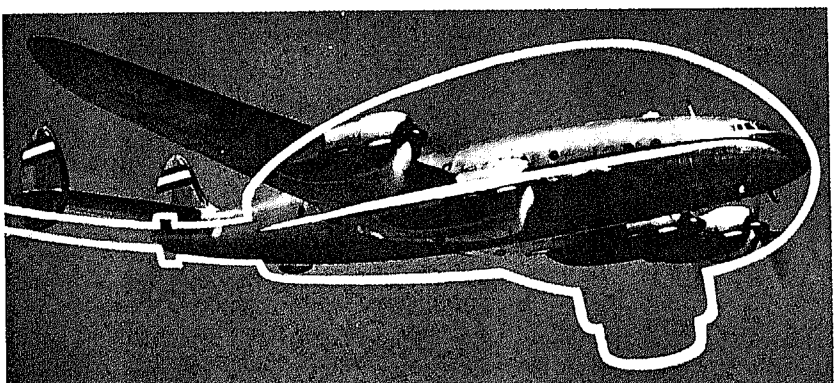


Figure 6
(a) Philishave, type 7735, known as the Egg (1948–1951). (b) Advertisement: "The aerodynamical world of the man with his Philishave."

Toward a Theory of Invention

By now, the picture has become quite complicated, and I want to conclude by suggesting a way of bringing some order in the chaos of artifacts, relevant social groups, technological frames, and variation, selection, and stabilization processes. As a first approximation I distinguish three possible developmental situations in which an artifact can be at a certain moment of time. These situations are characterized in terms of the concepts of social group, technological frame, and inclusion. In order to make the account more general, I draw on case studies other than Bakelite—the bicycle, the turbojet, and electric power distribution.

First, there is the situation in which no one social group with its accompanying technological frame is dominant.[9] An example of such a situation can be found, I think, in the development of the bicycle, around 1880. Although there were many social groups involved, it is hard to see any one of them dominating the field and structuring with its technological frame the identification of problems and the problem-solving strategies. The second situation is characterized by the dominance of one social group and the corresponding technological frame. Probably, this is the most common situation—"normal technology," to paraphrase Kuhn. The period from 1880 to 1920 in the development of (semi-)synthetic plastics provides an example, with the Celluloid technological frame being dominant. In the third situation, two or even more social groups with clearly developed technological frames are striving for dominance in the field. The difference from the first situation is that in that case the many relevant social groups do not yet have distinctive technological frames with respect to the artifact in question, whereas in the latter situation they have. Tom Hughes's analysis of the struggle between the dc and ac systems of electricity distribution offers an example of this third phase.

Having characterized three different phases, the next task is to specify which types of variation, selection, and stabilization processes can be expected to occur in each of the phases. Without being in any sense complete, I briefly discuss some possibilities.

When there is no dominant technological frame, as in the first type of development I have identified, the range of variants that might be put forward to solve a problem is not much constrained. The variation process will tend to be *radical* (see Hughes, this volume). Indeed , in the development of the bicycle around 1880 radically different variants were proposed to solve the safety problem. In the American Star bicycle (1881) the small steering wheel was positioned ahead of the high wheel; Lawson's Bicyclette (1879) had a chain drive on the smaller rear wheel. Thus "radically different" means that all aspects of the bicycle were subject to variation. Hardly any detail of the bicycle was taken for granted, not even the number of wheels (tri- and quatrocycles were constructed) or the method of foot propulsion (besides moving cranks in a circular motion, various lever devices were constructed, requiring a linear vertical motion of the feet). Selection and stabilization of variants will coincide almost totally in this situation. One of the more important stabilization processes in a situation without a clearly dominant social group and technological frame is *enrollment* (Callon and Law 1982). In such circumstances a social group tries to propagate its variant of solution by the enrollment of other groups to organize support for its artifact. One way to do this is by the *redefinition* of the problem (Pinch and Bijker, this volume). If an artifact (for example, the air tire) offers a solution to a problem that is not taken seriously by other powerful social groups, then the problem may be redefined in such a way that it does appeal to them. The problem for which the air tire first was considered to be a solution (the vibration problem) was redefined into a speed problem. The air tire also offered a solution to this problem, and because this problem was important to the racing cyclists, they were enrolled.

In the second development type, when one technological frame is dominant, it is fruitful to further distinguish highly from lowly included actors. Engineers with a relatively high inclusion in the technological frame will be sensitive to *functional failure* (Constant 1980) as an incentive to generating variants. A functional failure may occur when an artifact is used under new and more stringent conditions. Thus Celluloid's flammability presented such a functional failure of this plastic material when its use was extended to applications other than dentures, such as photographic film material. Actors with a high inclusion in the technological frame are bound to generate rather *conventional inventions* (Hughes, this volume)—improvements, optimalizations, adaptations. Thus a large part of the innovative effort of the Celluloid producers was directed toward rendering Celluloid less flammable by finding another solvent.

Actors with a relatively low inclusion in the technological frame interact to a smaller extent in terms of that frame. A consequence may be, as I have suggested in the case of Baekeland, that such actors do not draw much on the standard problem-solving strategies of that technological frame in which they have a low inclusion. Another consequence could be that such actors identify other problems more than actors with a high inclusion in the frame. For example, identification of a *presumptive anomaly* will typically occur among engineers with a relatively low inclusion in the technological frame. A presumptive anomaly, as Constant describes it,

> occurs in technology, not when the conventional system fails in any absolute or objective sense, but when assumptions derived from science indicate either that under some future conditions the conventional system will fail (or function badly) or that a radically different system will do a much better job. (Constant 1980, p. 15)

For example, aerodynamical theory in the 1920s suggested a future failure of the conventional piston engine–propeller system for aircraft propulsion. It suggested that proper streamlining would allow aircraft speeds to be increased at least twofold; the propeller would probably not function at the near-sonic speed that would be needed for such aircraft speeds; and theory suggested the feasibility of highly efficient gas turbines. My contention is that especially young, recently trained engineers are in a position to recognize and to react on a presumptive anomaly: They are trained within the technological frame but have low enough inclusion to question the basic assumptions of that frame.

Let me now consider the third situation, in which more than one technological frame is dominant. This is a situation that did not occur in the Bakelite case, at least not in the period I have concentrated on. For an illustration I therefore turn to another case. Around 1890 both the dc and the ac electricity distribution systems were commercially operated, sometimes even in the same town (Hughes 1983). The selection process in a situation like this is quite hectic, more so than in the first situation, in which there is no dominant technological frame and when less vested interests are at stake. Arguments, criteria, and considerations that are valid in one technological frame will not carry much weight in other frames. In such circumstances it seems that criteria that are external to both technological frames will play an important role in the selection process. This makes *rhetoric* a fitting selection mechanism in this third situation (Pinch and Bijker, this volume). Tom Hughes described such a rhetorical move in this "battle of currents." A dog is publicly electrocuted: first subjected to direct current of various voltages and then dispatched by alternating current. The objective was to persuade the audience that direct current, as opposed to alternating current, was relatively safe. As Hughes observes, often in such a "battle of the systems" (a competition between two powerful, equally dominant social groups with respective technological frames) no one wins a total victory. *Amortization of vested interests* is the stabilization process that will often occur in this situation (Hughes 1983). Of course, the rhetorical closure mechanism may also occur in the second situation, in which one technological frame is dominant. The key feature of this closure mechanism is, after all, that it brings about stabilization by using arguments that do not carry much weight within the actor's own technological frame but appeal forcefully to actors outside it.

I want to emphasize that the situations I have distinguished do not succeed one another in any fixed pattern. For example, Baekeland's first work on Bakelite can be understood, I think, as fitting in the second type of technology development—one technological frame and Baekeland being lowly included. But the subsequent development shows various characteristics that are more in line with the first type of development, in which no one technological frame is well developed.

Conclusion

I have tried to suggest an approach to a theoretical analysis of the development of technological artifacts that extends the descriptive model introduced by Pinch and Bijker (this volume). In the first section on the early history of plastics, two new theoretical concepts, technological frame and inclusion, were put forward. In the second section I discussed these concepts in some detail. A technological frame differs in two important aspects from paradigmlike concepts. First, it is applicable to all kinds of social groups, not just to groups of engineers. Second, a technological frame is an interactionist concept. Also, the differences between the concepts of (low) inclusion and marginality were discussed. In the third section these concepts were further illustrated by applying them to the Bakelite case. Finally, I proposed a kind of simplifying scheme to bring some sort of order to the newly created chaos. Three situations were distinguished to characterize the developmental process of an artifact at some stage: no dominant technological frame, one technological frame, and several dominant technological frames. It is stressed that these situations should not be interpreted as forming a rigid scheme of phases through which an artifact successively has to pass. Rather, it is a heuristic device to simplify the description of the "seamless web" of history. In doing so, I found that various concepts developed by historians of technology appeared to be useful. Thus the proposed approach not only brought some order out of disorder but also enabled us to relate different case studies to one other.

Notes

I am grateful to Michel Callon, Ed Constant, Ernst Homburg, Tom Hughes, Stephen Kline, Rachel Laudan, Simone Novaes, Trevor Pinch, Jeffrey Sturchio, Sharon Traweek, and my colleagues at De Boerderij for stimulating comments on previous drafts of this chapter. Of course, this substantial help does not make me less responsible for any remaining flaws in the argument.

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I am grateful to F. A. Becht, Naarden; the Museum Boymans–Van Beuningen, Rotterdam; and the National Museum of American History, Smithsonian Institution, Washington, D.C., for permission to reprint their material in the illustrations of this chapter.

1. The phrase "interpretative flexibility" may lead some readers to think, erroneously, that there is an independent and invariable reality of which only the interpretations may vary. To avoid this misunderstanding, perhaps we should have adopted the phrases "artifactual flexibility" and "factual flexibility." I thank Michel Callon for his comments on this point.

2. Stephen Kline has suggested that I baptize the concept as sociotechnical frame. Indeed, this describes its connotation more accurately. However, the phrase becomes even more elaborate than the concept of technological frame already is; for that reason I stick to the latter.

3. Similar to some extent are the concepts of figuration (Elias, 1970) and game (Crozier and Friedberg 1977; Van der Meer 1983, 1986; Wilhelm 1985; Wilhelm and Bolk 1986).

4. Wesley Shrum (1984) argued along similar lines in his analysis of technical systems. He refers to Ludwik Fleck (1935), whose "thought style" and "esoteric/exoteric circles" are at the roots of the concepts of technological frame and inclusion (Bijker 1984).

5. This was kindly pointed out to me by Jeffrey Sturchio, who is working on the history of Leo Baekeland and competition in the early American chemical industry.

6. In 1938 the Bakelite Gesellschaft mbH, Berlin, had a market survey carried out by the Gesellschaft für Konsumforschung EV, Berlin. The "retrospective market study" was organized by Intomart Qualitatief BV, Hilversum, the Netherlands. Results of both studies are reported in Kras et al. (1981). One should be careful in generalizing the results of these studies, because differences between using practices in different countries may be considerable (Kaufman 1963). However, it is my impression that these studies of the German and Dutch using practices are at least indicative of the situation in other countries.

7. In 1937 the Bakelite Corporation made a film called "The Fourth Kingdom," in which the production and various applications of Bakelite were shown in much detail. The film starts with a sonorous voice, arguing along the following lines: "Mineral, Vegetable, Animal—the three kingdoms of Nature. They served mankind

for ages, but now our modern industrial society finds them insufficient to fill all needs. It has to turn elsewhere; it turns to the fourth kingdom—Plastics" (followed by a crescendo in the symphonic music, of course). I am grateful to Robert Bud for showing me excerpts of this film.

8. Jenkins (1985) also proposes to link the history of technology and the history of art. In his analysis of some aspects of Edison's designs, he gives some intriguing suggestions.

9. Obviously, it is a matter of personal judgment by the historian to decide whether a technological frame is dominant or not. I can offer no quasi-objective measuring instruments for this dominance. In most cases adequate arguments can be given, I think, for the choice of relevant social groups, their technological frames, and their relative importance. For example, the difference between the first and the third situation is often clear. In the third situation, two powerful social groups, with technological frames that can be spelled out easily with respect to the artifacts in question, will have developed their two competing artifacts quite well. In the first situation, any bizarre variant may be considered and may eventually stabilize. For example, Dunlop's air tire became part and parcel of the Safety bicycle without ever having been propagated from the beginning by one powerful social group.